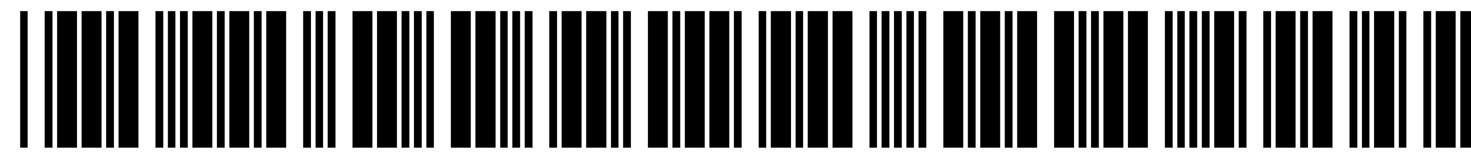
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Son et al.

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(54) **RIDGE-WAVEGUIDE SEMICONDUCTOR LASER DIODE**

(75) Inventors: **Joong-kon Son**, Seoul (KR); **Tae-hoon Jang**, Seoul (KR); **Youn-joon Sung**, Yongin-si (KR); **Tan Sakong**, Suwon-si (KR); **Ho-sun Paek**, Suwon-si (KR); **Sung-nam Lee**, Suwon-si (KR)

(73) Assignee: **Samsung Electronics Co., Ltd.**, Suwon-Si, Gyeonggi-Do (KR)

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
H01S 5/00 (2006.01)

(52) **U.S. Cl.** **372/45.01**; 372/46.01

(58) **Field of Classification Search** 372/45.012, 372/46.01, 75, 45.011, 46.011, 50.1, 43.01
See application file for complete search history.

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Primary Examiner—Minsun Harvey
Assistant Examiner—Tuan N. Nguyen
(74) *Attorney, Agent, or Firm*—Buchanan Ingersoll & Rooney PC

(57) **ABSTRACT**

A ridge-waveguide semiconductor laser diode with an improved current injection structure is provided. The ridge-waveguide semiconductor laser diode includes: a substrate; a lower multi-semiconductor layer formed on the substrate; an active layer formed on the lower multi-semiconductor layer; an upper multi-semiconductor layer having a ridge portion and formed on the active layer; and an upper electrode formed on the upper multi-semiconductor layer, wherein the upper electrode covers at least one side surface of the ridge portion.

21 Claims, 4 Drawing Sheets

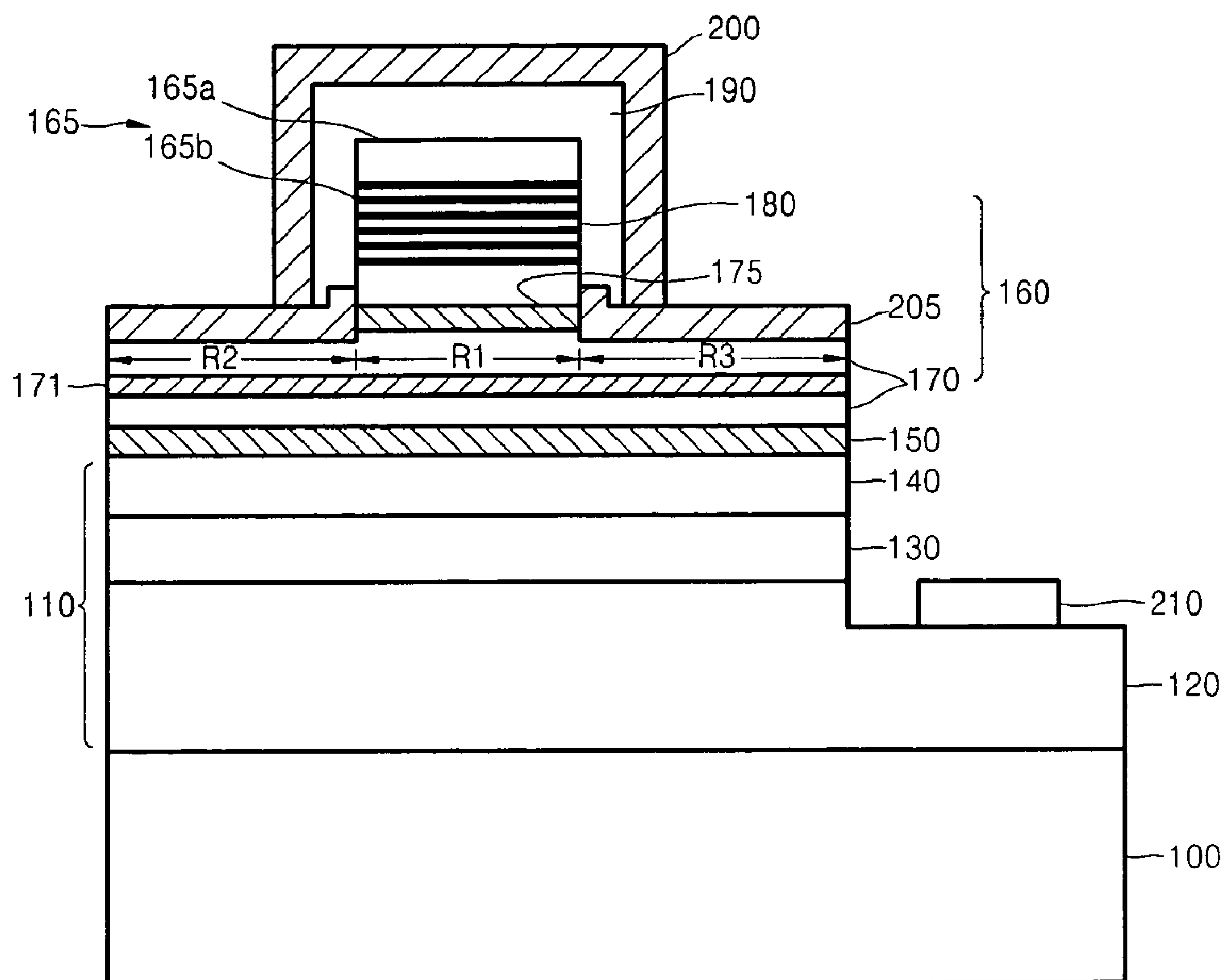


FIG. 1

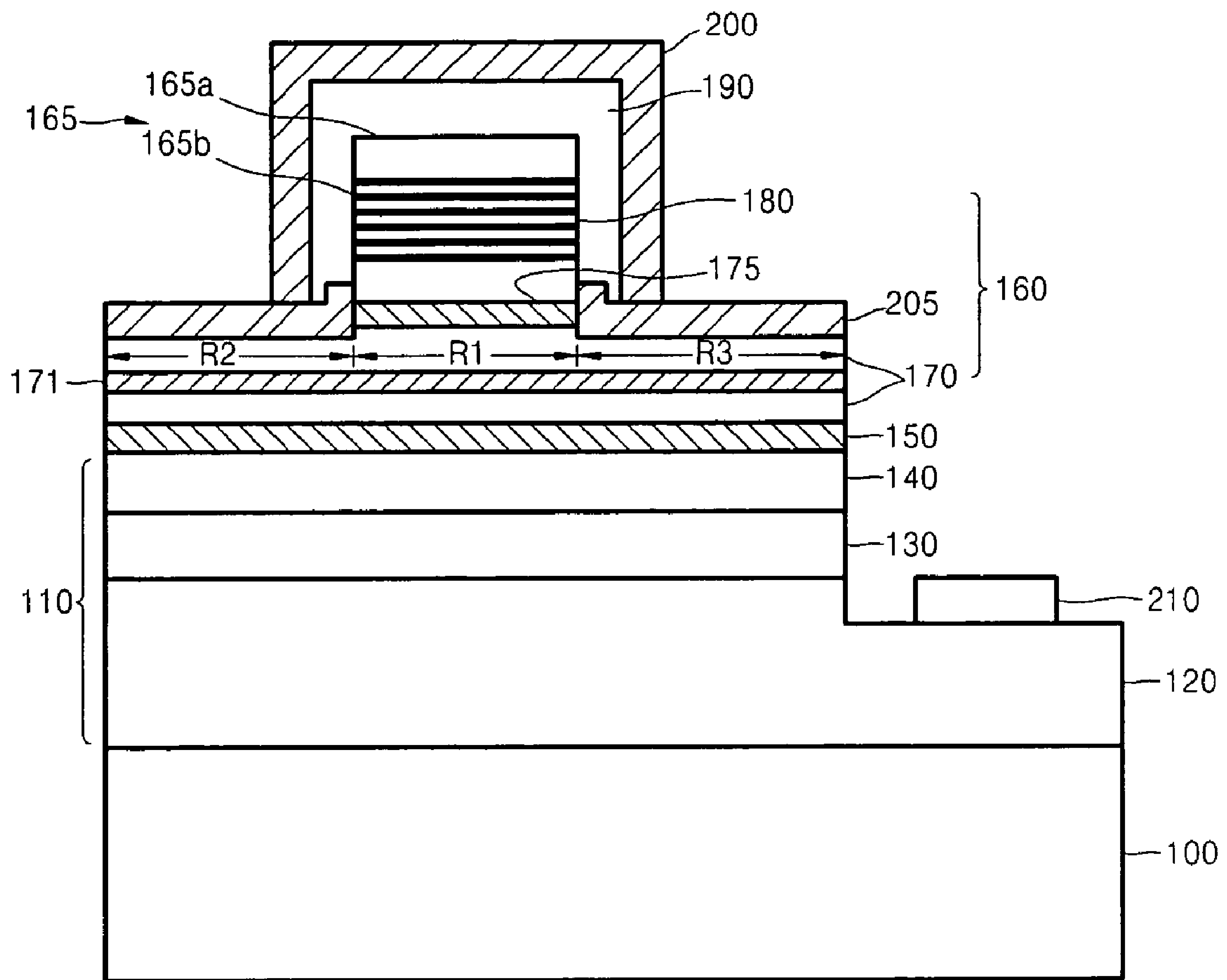


FIG. 2

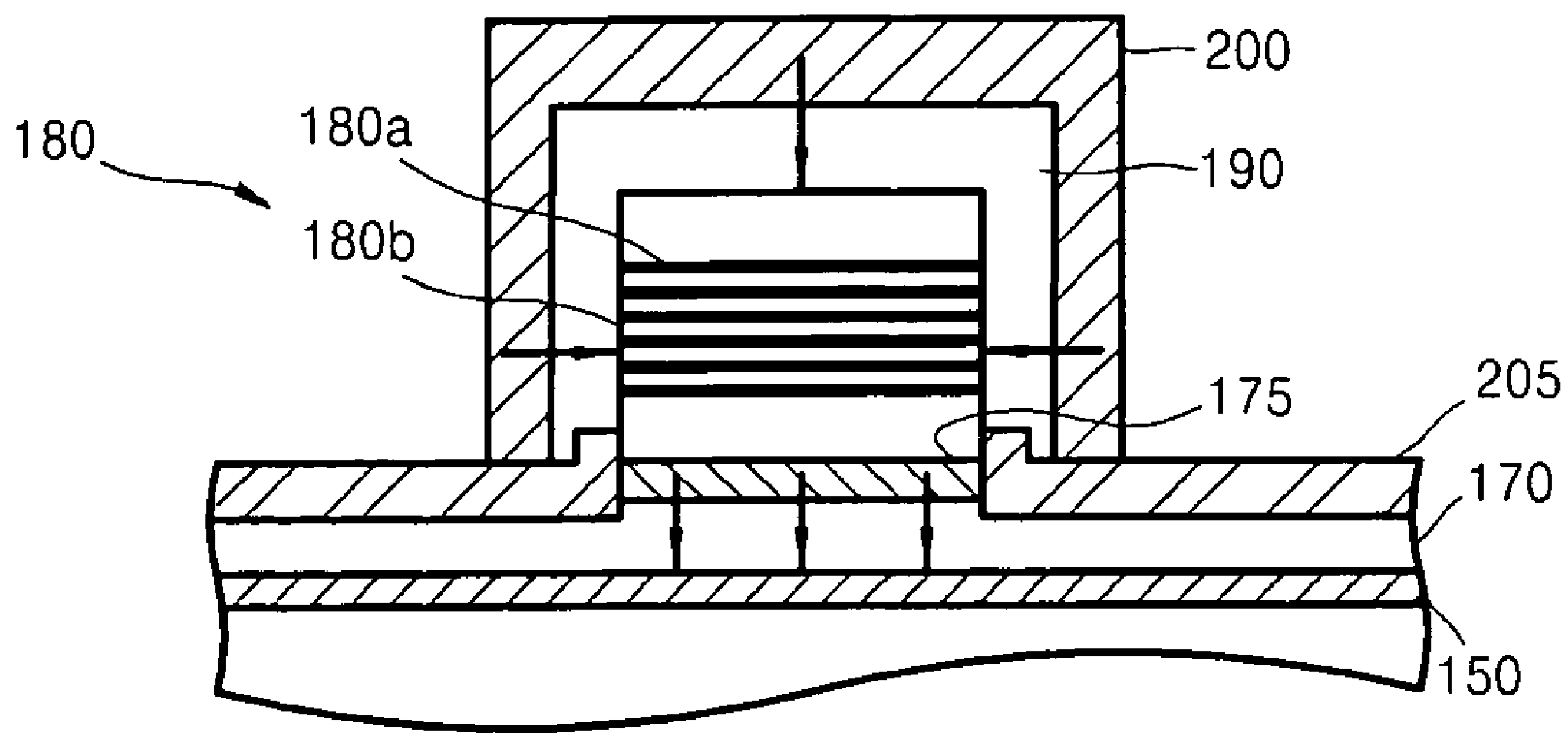


FIG. 3

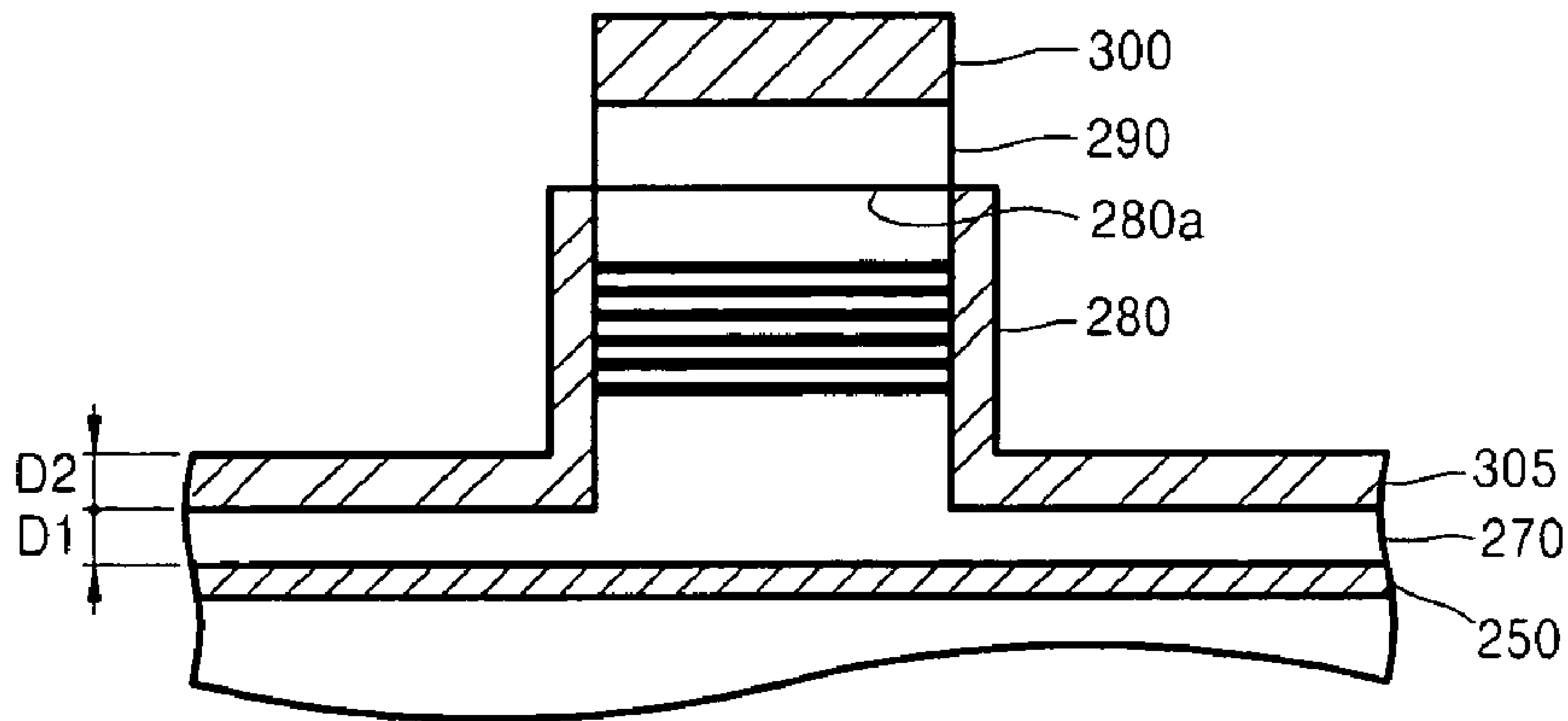


FIG. 4

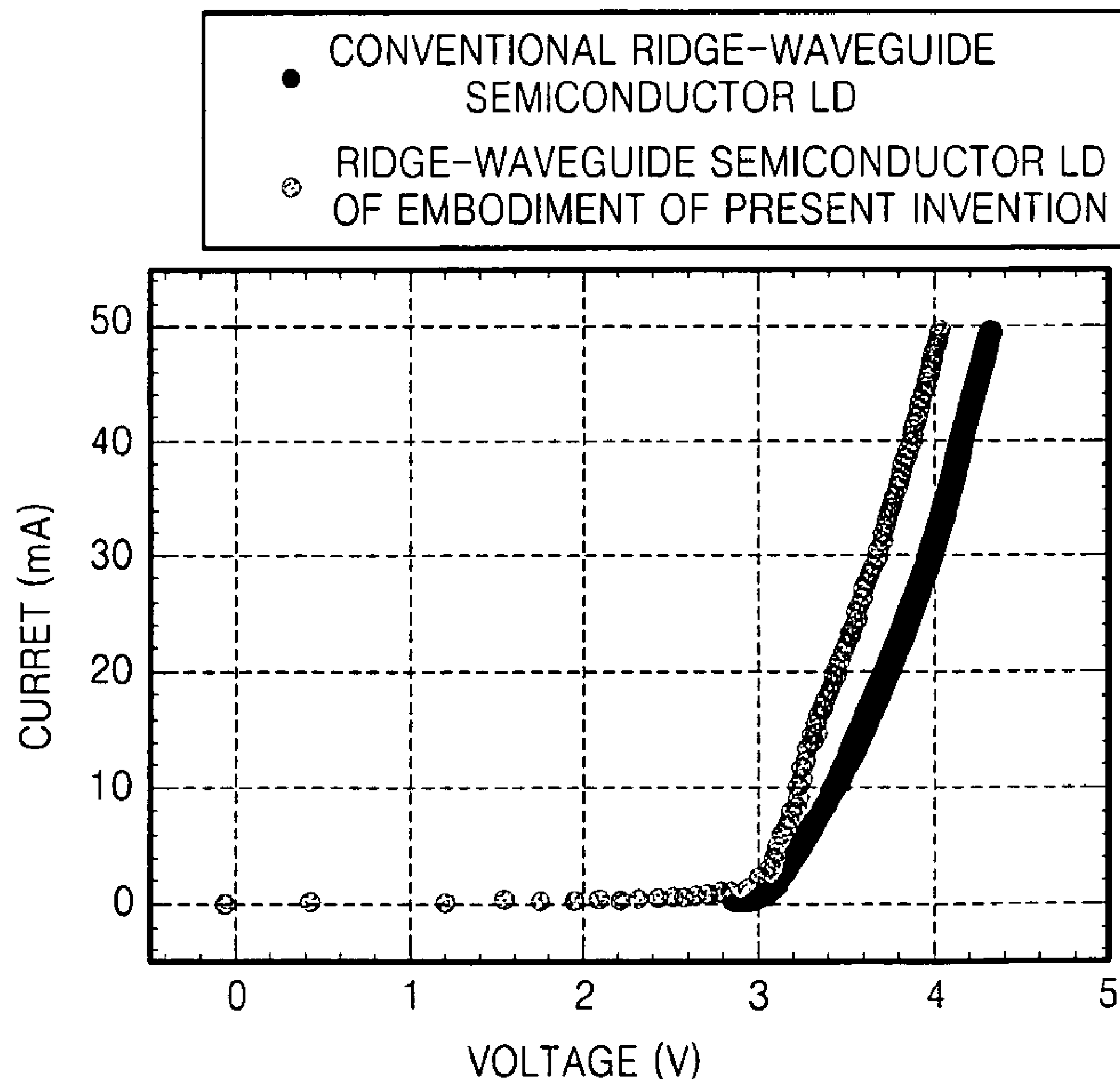
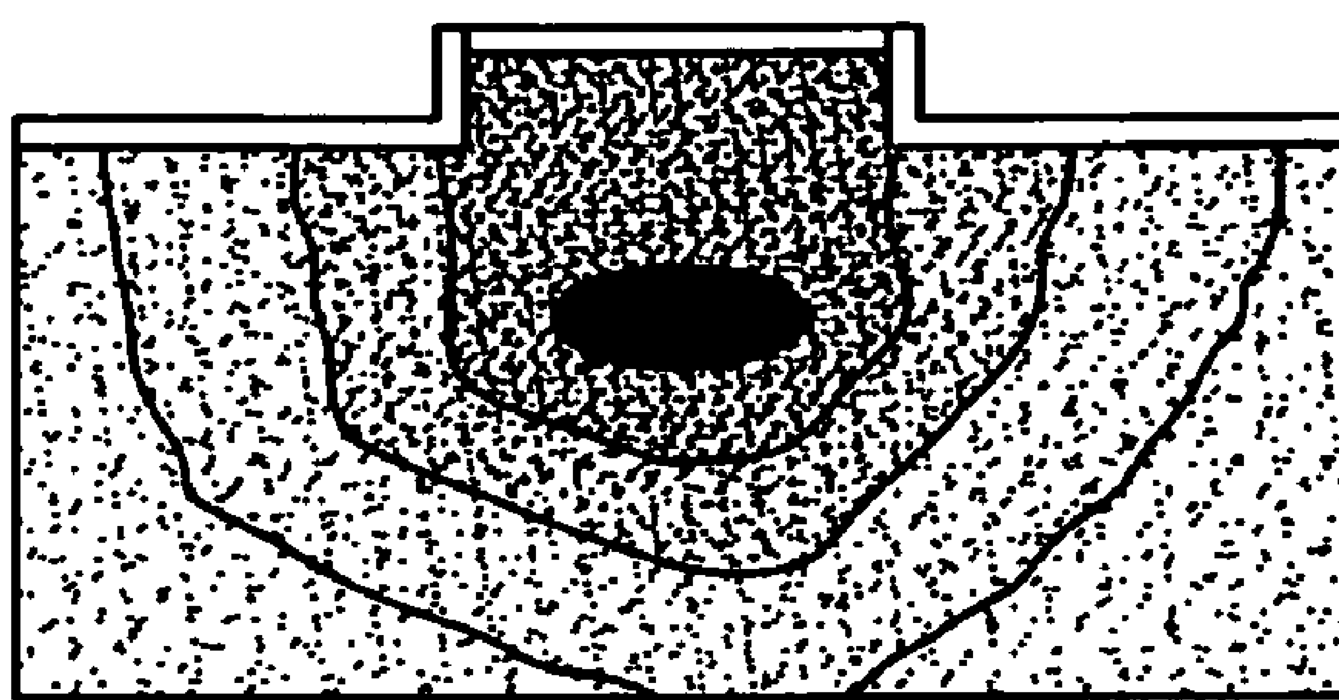


FIG. 5A



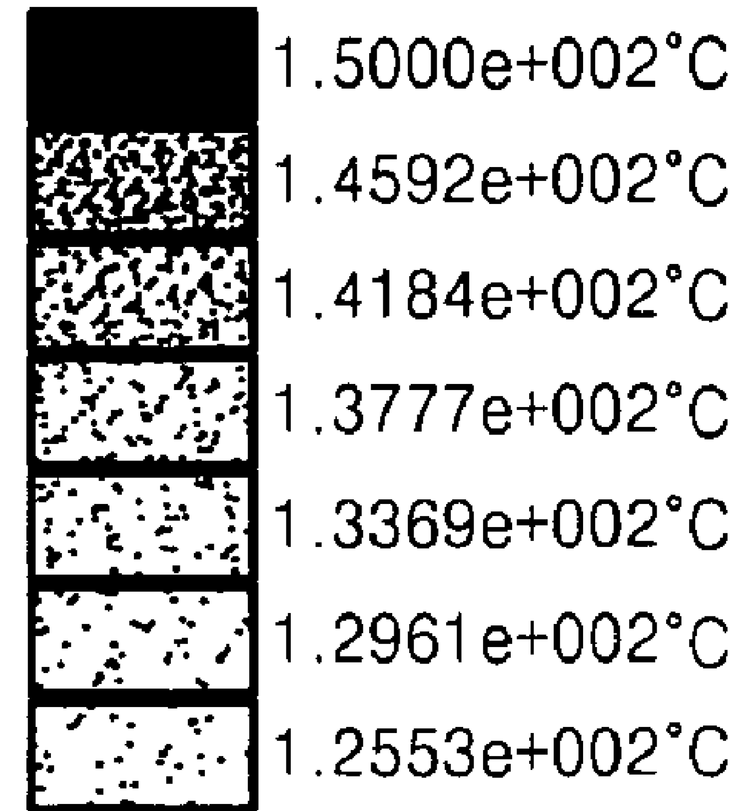
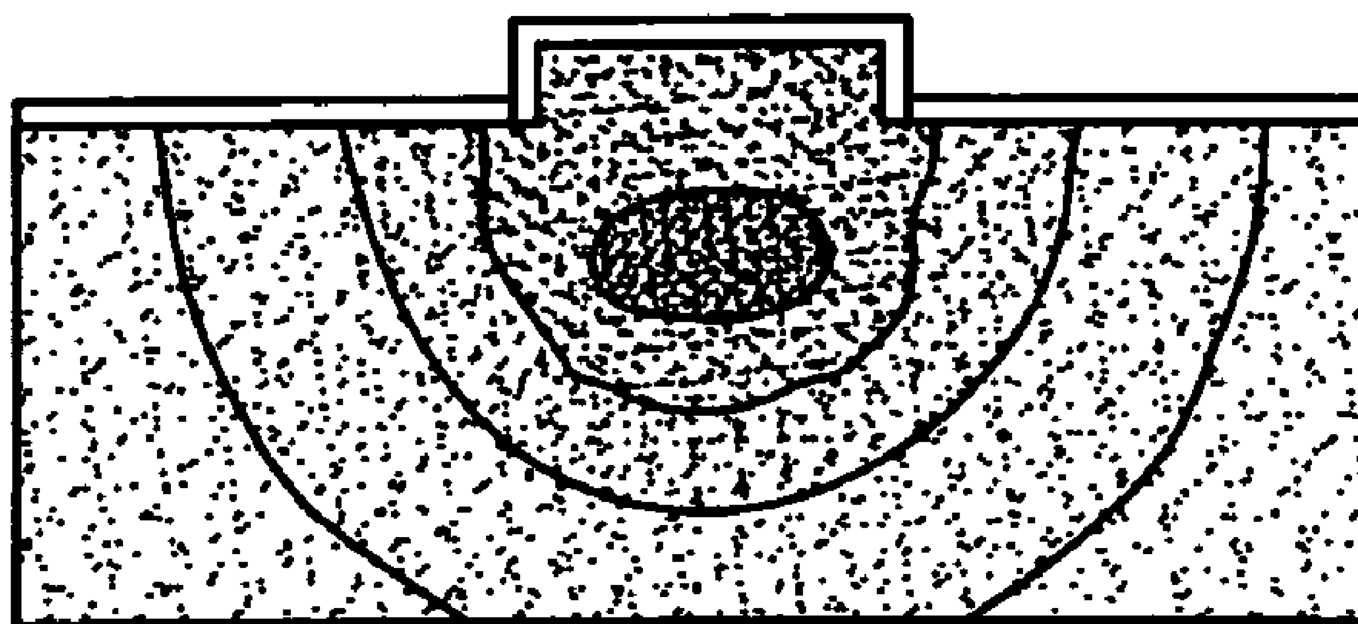
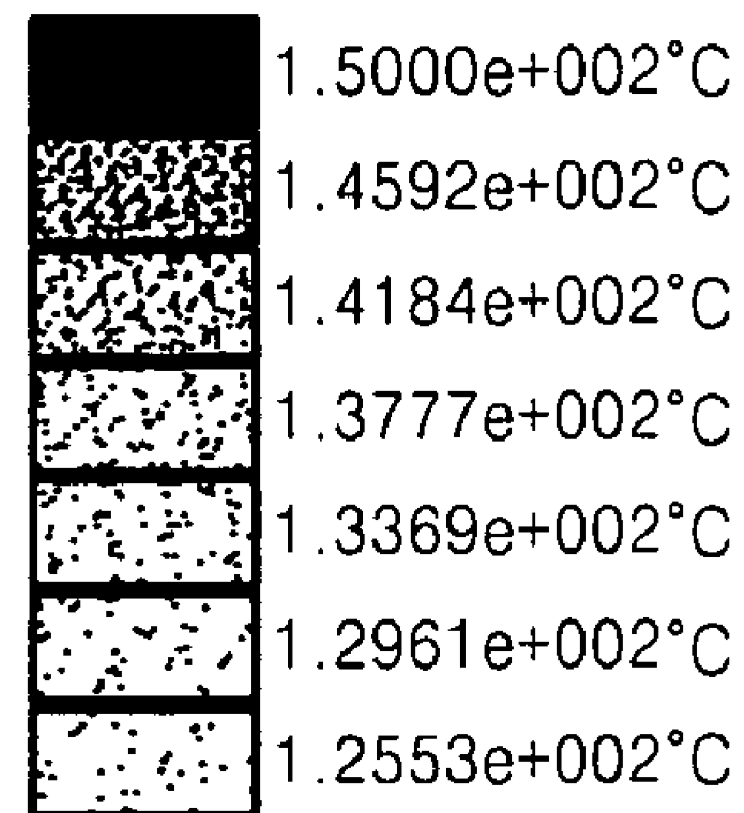


FIG. 5B





RIDGE-WAVEGUIDE SEMICONDUCTOR LASER DIODE

CROSS-REFERENCE TO RELATED PATENT APPLICATION

This application claims the benefit of Korean Patent Application No. 10-2006-0012602, filed on Feb. 9, 2006, in the Korean Intellectual Property Office, the disclosure of which is incorporated herein in its entirety by reference.

BACKGROUND OF THE DISCLOSURE

1. Field of the Disclosure

The present disclosure relates to a ridge-waveguide semiconductor laser diode (LD), and more particularly, to a ridge-waveguide semiconductor LD configured such that a current is laterally injected through side surfaces of a ridge portion.

2. Description of the Related Art

Semiconductor laser diodes (LDs) are widely used for transmitting, recording, and reading data in communication devices, such as optical communication devices, or in electronic devices, such as compact disk players (CDPs) or digital video disk players (DVDPs).

As the use of the semiconductor LDs has increased, semiconductor LDs having a low critical current value and a ridge portion that suppresses multiple transverse mode oscillation have been developed. The ridge portion is formed by upwardly protruding a p-type cladding layer and a p-type contact layer, and a current (holes) is vertically injected down into the ridge portion. However, the vertical current injection has a drawback in that high power is consumed and heat is generated due to the high resistance of a region doped with an impurity, such as magnesium (Mg), when the current (holes) passes through p-type semiconductor layers including the p type cladding layer and a p-type waveguide layer.

SUMMARY OF THE DISCLOSURE

The present invention may provide a ridge-waveguide semiconductor laser diode with an improved current injection structure.

According to an aspect of the present invention, there may be provided a ridge-waveguide semiconductor laser diode comprising: a substrate; a lower multi-semiconductor layer formed on the substrate; an active layer formed on the lower multi-semiconductor layer; an upper multi-semiconductor layer having a ridge portion and formed on the active layer; and an upper electrode formed on the upper multi-semiconductor layer, wherein the upper electrode covers at least one side surface of the ridge portion.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and advantages of the present invention are illustrated in detailed exemplary embodiments thereof with reference to the attached drawings in which:

FIG. **1** is a cross-sectional view of a ridge-waveguide semiconductor laser diode (LD) according to an embodiment of the present invention;

FIG. **2** is a cross-sectional view illustrating a current injection structure of the ridge-waveguide semiconductor LD of FIG. **1**;

FIG. **3** is a cross-sectional view of a conventional ridge-waveguide semiconductor LD;

FIG. **4** is a graph illustrating a relationship between an operating voltage and an operating current for the conven-

tional ridge-waveguide semiconductor LD of FIG. **3** and a ridge-waveguide semiconductor LD according to an embodiment of the present invention; and

FIGS. **5**A and **5**B are diagrams illustrating temperature distributions of the two LDs whose operating currents and voltages are illustrated in FIG. **4**.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

The present invention will now be described more fully with reference to the accompanying drawings, in which exemplary embodiments of the invention are shown.

FIG. **1** is a cross-sectional view of a ridge-waveguide semiconductor laser diode (LD) according to an embodiment of the present invention.

Referring to FIG. **1**, a lower multi-semiconductor layer **110** is formed on a substrate **100**. The lower multi-semiconductor layer **110** includes a lower contact layer **120**, a lower cladding layer **130**, and a lower waveguide layer **140**. An active layer **150**, an upper multi-semiconductor layer **160**, an upper contact layer **190**, and an upper electrode **200** are sequentially formed on one side of the lower contact layer **120**, and a lower electrode **210** is formed on the other side of the lower contact layer **120**.

The upper multi-semiconductor layer **160** may be divided into first through third regions R**1**, R**2**, and R**3**.

The first region R**1** has a ridge portion **165** protruding in a stripe shape from a central part of the upper multi-semiconductor layer **160**. The ridge portion **165** may protrude vertically or may be inclined to have a trapezoidal cross-section.

The upper multi-semiconductor layer **160** includes an upper waveguide layer **170** and an upper cladding layer **180**. A part of the upper waveguide layer **170** and the upper cladding layer **180** are formed on the ridge portion **165**.

An electron blocking layer **171** may be formed in the upper waveguide layer **170**. The energy level of the electron blocking layer **171** is much higher than that of the upper waveguide layer **170** such that the electron blocking layer **171** can prevent electron overflow.

A current spreading layer **175** may be embedded in the upper waveguide layer **170**. The current spreading layer **175** is disposed on the ridge portion **165** on the upper waveguide layer **170**. The current spreading layer **175** allows an injected current to spread over the entire surface thereof, such that the current can be uniformly injected into the active layer **150**.

The upper contact layer **190** and the upper electrode **200** cover at least one side surface **165***b* of the ridge portion **165**, such that the current can be injected through the side surface **165***b*. In order to inject the current through an upper surface **165***a* of the ridge portion **165**, the upper contact layer **190** and the upper electrode **200** may also be formed to cover the upper surface **165***a* of the ridge portion **165**.

The second and third regions R**2** and R**3** are formed on parts of the upper waveguide layer **170** outside the ridge portion **165**, and insulating layers **205** are formed on the second and third regions R**2** and R**3**. The insulating layers **205** cover both lateral edges of the current spreading layer **175**. The insulating layers **205** insulate the upper contact layer **190** from the upper waveguide layer **170** and the current spreading layer **175**.

The ridge-waveguide semiconductor LD of the present embodiment may be a GaN-based semiconductor LD. In detail, the ridge-waveguide semiconductor LD may be formed as described hereafter.

The substrate **100** may be formed of sapphire (Al_2O_3), gallium nitride (GaN), silicon (Si), aluminium nitride (AlN), or silicon carbide (SiC).

The lower contact layer **120** may be formed of n-GaN. The lower cladding layer **130** may be formed of n-$Al_xGa_{1-x}N$ ($0 \leqq x<1$). The lower waveguide layer **140** may be formed of n-$In_xGa_{1-x}N$ ($0 \leqq x<1$). The active layer **150** may be formed of $In_xGa_{1-x}N$ ($0<x<1$) and have a single-quantum well or multi-quantum well structure. The upper waveguide layer **170** may be formed of p-$In_xGa_{1-x}N$ ($0 \leqq x<1$). The electron blocking layer **171** may be formed of a p-$Al_xGa_{1-x}N$ ($0<x<1$) compound semiconductor.

The current spreading layer **175** may have a hetero-junction structure of a p-GaN layer and a p-InGaN layer so that the energy level of the current spreading layer **175** can be much lower than the energy level of the upper waveguide layer **170**.

The upper cladding layer **180** may be a single layer formed of p-$Al_xGa_{1-x}N$ ($0 \leqq x<1$) or may have a superlattice structure formed by alternately and repeatedly stacking p-$Al_xGa_{1-x}N$ ($0 \leqq x<1$) layers having different aluminum (Al) composition ratios. For example, the upper cladding layer **180** may have a superlattice structure where a p-$Al_{0.08}Ga_{0.92}N$ layer and a p-GaN layer are repeatedly stacked. The superlattice structure leads to a reduction in both carrier injection resistance and the risk of cracks, and thus the upper cladding layer **180** can be stably crystal-grown and a high optical confinement effect can be maintained.

The upper contact layer **190** improves ohmic contact properties between the upper cladding layer **180** and the upper electrode **200**, and may be formed by sequentially stacking p^+-GaN/Pd layers on an upper surface **180*a*** and side surfaces **180*b*** of the upper cladding layer **180**.

The upper electrode **200** may be made of a highly conductive metallic material, for example, a commonly used electrode material. In detail, the upper electrode **200** may be a single layer formed of Au, Ni, Ti, or Al, or may be a double layer of these materials.

The insulating layers **205** may be formed of an insulting material such as SiO_2.

The operation of the ridge-waveguide semiconductor LD according to the present embodiment will now be explained with reference to FIG. **2**. FIG. **2** is a cross-sectional view illustrating a current injection structure of the ridge-waveguide semiconductor LD of FIG. **1**.

Referring to FIG. **2**, when a voltage is applied to the upper electrode **200**, a current, that is, carriers are injected into the upper contact layer **190**. When the layers formed on the active layer **150** are p-type layers as described above, the carriers injected into the upper contact layer **190** are holes. Since the upper electrode **200** and the upper contact layer **190** cover the upper cladding layer **180**, the carriers are injected through the side surfaces **180*b*** as well as through the upper surface **180*a*** of the upper cladding layer **180**. When the current is injected through the side surfaces **165*b*** of the ridge portion **165** as shown in FIG. **2**, a path through which the carriers pass in the p-type upper cladding layer **180** with high resistance is shortened, thereby reducing the carrier injection resistance. Also, the current path when the current is injected through the upper surface **180*a*** and the side surfaces **180*b*** has a larger area than the current path when the current is injected through only the upper surface **180*a***, thereby reducing resistance. As a result, since the same power can be provided at a lower operating voltage than that when a conventional ridge-waveguide semiconductor LD is used, the ridge-waveguide semiconductor LD of the present embodiment is superior to the conventional ridge-waveguide semiconductor LD in terms of the operating voltage and power. In addition, since the current injected through the side surfaces **180*b*** spreads while passing through the current spreading layer **175**, the current is prevented from flowing to a side.

Also, when the upper cladding layer **180** has a superlattice structure formed by alternately stacking p-$Al_xGa_{1-x}N$ ($0 \leqq x1$) layers having different Al composition ratios, the carriers pass through the upper cladding layer **180** by tunneling or carrier overflow, thereby further reducing the injection resistance.

Moreover, since the upper electrode **200** made of a metallic material with high thermal conductivity covers both the side surfaces **180*b*** as well as the upper surface **180*a*** of the upper cladding layer **180**, the ridge-waveguide semiconductor LD of the present embodiment has high heat dissipation capability.

Furthermore, the ridge-waveguide semiconductor LD of the present embodiment can improve the electrical characteristics of a long wavelength semiconductor LD. In general, semiconductor LDs emitting a blue or green laser beam with a long wavelength use a low temperature p-type semiconductor layer. The low temperature p-type semiconductor layer is inferior in terms of electrical characteristics to a high temperature p-type semiconductor layer in that the hole concentration is low and resistance is high in the low temperature p-type semiconductor. The ridge-waveguide semiconductor LD of the present embodiment can improve the electrical characteristics of the long-wavelength semiconductor LD that uses the low temperature semiconductor layer, by improving a current injection mechanism.

The effect of a ridge-waveguide semiconductor LD according to an embodiment of the present invention compared to a conventional ridge-waveguide semiconductor LD will be explained hereafter.

Conventional Ridge-waveguide Semiconductor LD

A conventional ridge-waveguide semiconductor LD having a vertical current injection structure as shown in FIG. **3** was manufactured. The conventional ridge-waveguide semiconductor LD was a III group nitride-based semiconductor LD. An upper waveguide layer **270** was formed on an active layer **250**. An upper cladding layer **280** upwardly protruded from a central part of the upper waveguide layer **270**. The upper cladding layer **280** constitutes a ridge portion. An upper contact layer **290** and an upper electrode **300** were sequentially stacked on an upper surface **280*a*** of the upper cladding layer **280**. Insulating layers **305** were formed on side surfaces of the upper cladding layer **280** and upper surfaces of the upper waveguide layer **270** outside the ridge portion. The thickness D**1** of the upper waveguide layer **270** outside the ridge portion was approximately 500 Å, and the thickness D**2** of the insulating layers **305** was approximately 1500 Å or less.

Ridge-Waveguide Semiconductor LD of the Present Embodiment

A ridge-waveguide semiconductor LD allowing both vertical and lateral injection according to an embodiment of the present invention as shown in FIG. **2** was manufactured. The ridge-wavelength semiconductor LD of the present embodiment was similar to the conventional ridge-waveguide semiconductor LD except that an upper contact layer **190** and an upper electrode **200** were formed to cover side surfaces **165*b*** as well as an upper surface **165*a*** of an upper cladding layer **180**, as shown in FIGS. **1** and **2**.

The characteristics of the manufactured two LDs will now be explained with reference to FIG. **4** and FIGS. **5**A and **5**B.

FIG. **4** is a graph illustrating a relationship between an operating voltage and an operating current for the conventional ridge-waveguide semiconductor LD of FIG. **3** and a ridge-waveguide semiconductor LD according to an embodiment of the present invention. Referring to FIG. **4**, in the conventional ridge-waveguide semiconductor LD, the operating voltage required to produce a current of 50 mA was 4.36 V, whereas in the ridge-waveguide semiconductor LD of the present embodiment, the operating voltage required to produce a current of 50 mA was 4.03V, about 0.3 V lower than 4.36 V. That is, while the injection resistance of the conventional ridge-waveguide semiconductor LD was 17.0 Ω, the injection resistance of the ridge-waveguide semiconductor LD of the present embodiment was 15.5 Ω.

FIGS. **5**A and **5**B are diagrams illustrating temperature distributions of the conventional ridge-waveguide semiconductor LD and the ridge-waveguide semiconductor LD of the present embodiment, respectively. Referring to FIGS. **5**A and **5**B, the temperature of the ridge-waveguide semiconductor LD of the present embodiment was generally lower than the temperature of the conventional ridge-waveguide semiconductor LD. While the conventional ridge-waveguide semiconductor LD had a surface temperature of 130.47° C., the ridge-waveguide semiconductor LD of the present embodiment had a surface temperature of 117.93° C., about 10% lower than 130.47° C. This is because the ridge-waveguide semiconductor of the present embodiment reduces heat generation in the upper cladding layer due to the low injection resistance of the upper cladding layer and can discharge heat through the upper electrode made of metal formed on the side surfaces of the upper cladding layer.

As described above, the ridge-waveguide semiconductor LD according to the present invention has the following advantages.

First, since a current is injected through both the side surfaces of the ridge portion, injection resistance can be reduced and high operating voltage and power can be achieved.

Second, since the upper electrode made of a metallic material covers both the side surfaces of the ridge portion, efficient heat dissipation can be ensured.

While the present invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present invention as defined by the following claims.

What is claimed is:

1. A ridge-waveguide semiconductor laser diode comprising:

a substrate;

a lower multi-layered semiconductor formed on the substrate;

an active layer formed on the lower multi-layered semiconductor;

an upper multi-layered semiconductor having a multi-layered semiconductor ridge portion and formed on the active layer, the ridge portion having an upper surface substantially parallel to layers of the upper multi-layered semiconductor and side surfaces transverse to the upper surface of the ridge portion and the layers of the upper multi-layered semiconductor, and the ridge portion including an upper cladding layer;

an upper electrode formed on the upper multi-layered semiconductor; and

an upper contact layer formed between the upper electrode and the upper cladding layer, the upper cladding layer including side surfaces respectively corresponding to the side surfaces of the ridge portion, and an upper surface within the ridge portion,

wherein the upper electrode covers at least one of the side surfaces of the ridge portion transverse to the upper surface of the ridge portion and the layers of the upper multi-layered semiconductor, and is configured to inject current through the at least one side surface of the ridge portion, and

wherein the upper contact layer is formed between the upper electrode and the side surfaces and the upper surface of the upper cladding layer.

2. The ridge-waveguide semiconductor laser diode of claim **1**, wherein the upper electrode covers the at least one side surface and the upper surface of the ridge portion.

3. The ridge-waveguide semiconductor laser diode of claim **1**, wherein the upper multi-layered semiconductor includes an upper waveguide layer, and the ridge portion includes a part of the upper waveguide layer.

4. The ridge-waveguide semiconductor laser diode of claim **3**, wherein the upper cladding layer has a superlattice structure formed by alternately and repeatedly stacking $Al_xGa_{1-x}N$ ($0 \leqq x < 1$) layers having different aluminum (Al) composition ratios.

5. The ridge-waveguide semiconductor laser diode of claim **3**, wherein current applied to the upper electrode is injected through a plurality of side surfaces of the upper cladding layer.

6. The ridge-waveguide semiconductor laser diode of claim **1**, further comprising a current spreading layer embedded in the upper waveguide layer and formed in the ridge portion.

7. The ridge-waveguide semiconductor laser diode of claim **6**, wherein the current spreading layer has a heterojunction structure of a p-GaN layer and a p-InGaN layer.

8. The ridge-waveguide semiconductor laser diode of claim **6**, further comprising insulating layers for insulating the upper contact layer from the upper waveguide layer and the current spreading layer.

9. The ridge-waveguide semiconductor laser diode of claim **6**, wherein current applied the upper electrode is injected through a plurality of side surfaces of the upper cladding layer, and the current spreading layer embedded in the upper waveguide layer is configured to spread the injected current across the sides of the upper cladding layer.

10. The ridge-waveguide semiconductor laser diode of claim **1**, wherein the lower multi-layered semiconductor is formed of an n-type semiconductor, and the upper multi-layered semiconductor is formed of a p-type semiconductor.

11. The ridge-waveguide semiconductor laser diode of claim **1**, wherein the lower multi-layered semiconductor, the active layer, and the upper multi-layered semiconductor are formed of GaN-based materials.

12. The ridge-waveguide semiconductor laser diode of claim **1**, wherein:

the upper multi-layered semiconductor includes an upper cladding layer within the ridge portion;

the upper cladding layer includes side surfaces respectively corresponding to the side surfaces of the ridge portion, and an upper surface within the ridge portion; and

the upper electrode covers the side surfaces of the upper cladding layer.

13. The ridge-waveguide semiconductor laser diode of claim **12**, wherein current applied to the upper electrode is injected through the side surfaces of the upper cladding layer.

14. The ridge-waveguide semiconductor laser diode of claim **12**, wherein the upper electrode further covers the upper surface of the upper cladding layer.

15. The ridge-waveguide semiconductor laser diode of claim **14**, wherein current applied to the upper electrode is injected through the side surfaces and the upper surface of the upper cladding layer.

16. The ridge-waveguide semiconductor laser diode of claim **14**, further comprising an upper contact layer formed between the upper electrode and the upper cladding layer.

17. The ridge-waveguide semiconductor laser diode of claim **16**, wherein the upper electrode covers side surfaces and an upper surface of the upper contact layer respectively covering the side surfaces and the upper surface of the upper cladding layer.

18. The ridge-waveguide semiconductor laser diode of claim **14**, wherein the upper electrode covering the side surfaces and the upper surface of the upper cladding layer is configured to dissipate heat from the side surfaces and the upper surface of the upper cladding layer.

19. The ridge-waveguide semiconductor laser diode of claim **1**, wherein the ridge portion of the upper multi-layered semiconductor protrudes from a central region of the upper multi-layered semiconductor.

20. The ridge-waveguide semiconductor laser diode of claim **1**, wherein the ridge portion of the upper multi-layered semiconductor is substantially rectangular.

21. The ridge-waveguide semiconductor laser diode of claim **1**, wherein the ridge portion has a trapezoidal cross-section.

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